DEVICE AND METHOD OF CREATING HYDRODYNAMIC CAVITATION IN FLUIDS

Background

[0001] The present application relates to a device and method for creating hydrodynamic cavitation in fluids. This device and method may find application in mixing, synthesis, assisting in chemical reactions, and sonochemical reactions in the chemical, food, pharmaceuticals, cosmetics processing, and other types of industry.

[0002] Cavitation is the formation of bubbles and cavities within a liquid stream resulting from a localized pressure drop in the liquid flow. If the pressure at some point decreases to a magnitude under which the liquid reaches the boiling point for this fluid, then a great number of vapor-filled cavities and bubbles are formed. As the pressure of the liquid then increases, vapor condensation takes place in the cavities and bubbles, and they collapse, creating very large pressure impulses and very high temperatures. According to some estimations, the temperature within the bubbles attains a magnitude on the order of 5000°C and a pressure of approximately 500 kg/cm^2. Cavitation involves the entire sequence of events beginning with bubble formation through the collapse of the bubble. Because of this high energy level, cavitation has been studied for its ability to mix materials and aid in chemical reactions.

[0003] There are several different ways to produce cavitation in a fluid. The way known to most people is the cavitation resulting from a propeller blade moving at a critical speed through water. If a sufficient pressure drop occurs at the blade surface, cavitation will result. Likewise, the movement of a fluid through a restriction such as an orifice plate can also generate cavitation if the pressure drop across the orifice is sufficient. Both of these methods are commonly referred to as hydrodynamic cavitation. Cavitation may also be generated in a fluid by the use of ultrasound. A sound wave consists of compression and decompression cycles. If the pressure during the decompression cycle is low enough, bubbles may be formed. These bubbles will grow during the decompression cycle and contract or even implode during the compression cycle.

Brief Description Of The Drawings

[0004] It will be appreciated that the illustrated boundaries of elements (e.g., boxes or groups of boxes) in the figures represent one example of the boundaries. One of ordinary skill in the art will appreciate that one element may be designed as multiple elements or that multiple elements may be designed as one element. An element shown as an internal component of another element may be implemented as an external component and vice versa.

[0005] Further, in the accompanying drawings and description that follow, like parts are indicated throughout the drawings and description with the same reference numerals, respectively. The figures are not drawn to scale and the proportions of certain parts have been exaggerated for convenience of illustration.

[0006] FIG. 1 illustrates a longitudinal cross-section of one embodiment of a device 100 for creating hydrodynamic cavitation.

[0007] FIG. 2 illustrates a longitudinal cross-section of another embodiment of a device 200 for creating hydrodynamic cavitation.

[0008] FIG. 3 illustrates a longitudinal cross-section of another embodiment of a device 300 for creating hydrodynamic cavitation.

[0009] FIG. 4 illustrates a longitudinal cross-section of another embodiment of a device 400 for creating hydrodynamic cavitation.

[0010] FIG. 5 illustrates a longitudinal cross-section of another embodiment of a device 500 for creating hydrodynamic cavitation.

Detailed Description

[0011] **FIG. 1** illustrates a longitudinal cross-section of one embodiment of a device **100** for creating hydrodynamic cavitation. The device **100** can include at least one wall **105** having an inner surface **110** that defines a flow-through channel or chamber **115**. For example, the wall **105** can be a cylindrical wall that defines a flow-through channel having a circular cross-section. It will be appreciated that the cross-section of flow-through channel **115** may take the form of other geometric shapes such as square, rectangular, hexagonal, or any other complex shape.

[0012] The flow-through channel **115** can further include an inlet **120** configured to introduce a liquid into the device **100** along a path, represented by arrow **A,** and an outlet **125** configured to exit the liquid from the device **100**.

[0013] Situated within the flow-through channel **115** is a cavitation chamber **130** defined by a front wall **135** oriented substantially perpendicular to the flow-through channel **115**, at least one side wall **140** oriented substantially parallel to the flow-through channel **115**, and an exit opening **145** in communication with the outlet **125**. It will be appreciated that although the illustrated cavitation chamber **130** is cylindrical in shape, it is contemplated that any shape may be possible provided that the liquid stream is permitted to enter the cavitation chamber **130**. Suitable shapes may include cubical, conical, spherical, semi-spherical, or rectangular.

[0014] In one embodiment, the side wall **140** can include a first orifice **150** configured to permit the introduction of a first liquid stream into the cavitation chamber **130** and a second orifice **155**, oriented opposite the first orifice **150**, and configured to permit the introduction of a second liquid stream into the cavitation chamber **130**. For example, the first orifice **150** and the second orifice **155** can directly face each other and share the same centerline $\mathbf{C_L}$.

[0015] In one embodiment, the diameter of the first orifice **150** can be sufficiently smaller than the second orifice **155** to permit penetration of the first liquid stream into the second liquid stream. For example, the diameter of the first orifice **150** can be at least 10% less than the diameter of the second orifice **155** to provide adequate penetration of the first liquid stream into the second liquid stream.

[0016] The cavitation chamber **130** can also include a flange **160** in communication with the side wall **140** and the flow-through channel **115** to direct fluid into the cavitation chamber **130** and restrict fluid from exiting the flow-through channel **115** without being directed into the first orifice **150** or second orifice **155**.

[0017] In operation, a hydrodynamic liquid stream can move along the **A** direction through the inlet **120** and flow into the flow-through channel **115**. As the liquid stream approaches the front wall **135**, the liquid stream can be directed outwards towards the inner surface **110** of the wall **105**. One portion of the liquid stream, indicated by arrow **B**, can pass around the front wall **135** and enter the first orifice **150** forming a liquid jet **165** (hereinafter referred to as "smaller liquid jet **165**" because this liquid jet exits the smaller diameter orifice **150**). Additionally, the other portion of the liquid stream, indicated by arrow **C**, can pass around the front wall **135** and enter the second orifice **155** forming a liquid jet **170** (hereinafter referred to as "larger liquid jet **170**" because this liquid jet exits the larger diameter orifice **155**).

[0018] Both the smaller liquid jet **165** and the larger liquid jet **170** can flow into the cavitation chamber **130** where they impinge along centerline $\mathbf{C_L}$. Once the smaller liquid jet **165** and the larger liquid jet **170** impinge, the smaller liquid jet **165** can penetrate and interact with the larger liquid jet **170** thereby creating a high shear intensity vortex contact layer **175** between the liquid jets **165**, **170**. As a result of this penetration and interaction, cavitation caverns and bubbles are created in the high shear intensity vortex contact layer **175**. During the collapse of the cavitation caverns and bubbles, high localized pressures, up to 1000 MPa, arise and the level of energy dissipation in the flow-through channel **115** attains a magnitude in the range of 1^{10} - 1^{15} watt/kg. Under these physical conditions in the liquid, on the boundary of the bubble and inside the bubble itself in the gas phase, chemical reactions proceed such as oxidation, disintegration, synthesis, etc. After the cavitation bubbles collapse, the liquid can be transported from the cavitation chamber **130** through the exit orifice **145** and exit the outlet **125**, represented by arrow **D**.

[0019] In one embodiment, the smaller liquid jet **165** can penetrate and interact with the larger liquid jet **170** when the relative velocity between the two liquid jets **165**, **170** reaches a certain threshold. For example, the smaller liquid jet **165** can penetrate and interact with the

larger liquid jet **170** when the relative velocity between the two liquid jets **165, 170** is at least 10 meters/second. It will be appreciated that the relative velocity between the two liquid jets **165, 170** can be less than or greater than 10 meters/second depending on the viscosity, density, and/or temperature of the liquid stream.

[0020] **FIG. 2** illustrates a longitudinal cross-section of another embodiment of a device **200** for creating hydrodynamic cavitation. The device **200** is very similar in structure and function to the device **100** described above and illustrated in **FIG. 1**, except that the device **200** includes a second pair of opposing orifices **205, 210** and a third pair of opposing orifices **215, 220** in the side wall **140**. As in the case of the device **100**, each pair of opposing orifices can have different sized diameters.

[0021] **FIG. 3** illustrates a longitudinal cross-section of another embodiment of a device **300** for creating hydrodynamic cavitation. The device **300** is very similar in structure and function to the device **100** described above and illustrated in **FIG. 1**, except that the device **300** includes a second cavitation chamber **305** provided in series with the first cavitation chamber **130** in the flow-through channel **115**. The second cavitation chamber **305** can be defined by a front wall **310**, at least one side wall **315** having a pair of opposing jetting orifices **325, 330**, and an exit opening **335**. Like device **100**, the pair of opposing orifices **325, 330** can have different sized diameters.

[0022] **FIG. 4** a longitudinal cross-section of another embodiment of a device **400** for creating hydrodynamic cavitation. The device **400** can include at least one wall **405** having an inner surface **410** that defines a chamber **415**. For example, the wall **405** can be a cylindrical wall that defines a flow-through channel having a circular cross-section. It will be appreciated that the cross-section of the chamber **415** may take the form of other geometric shapes such as square, rectangular, hexagonal, or any other complex shape. The chamber **415** can further include an outlet **417** configured to exit the liquid from the device **400**.

[0023] In one embodiment, the wall **405** can include a first orifice **420** configured to permit the introduction of a first liquid stream into the chamber **415** and a second opposing orifice **425** configured to permit the introduction of a second liquid stream into the chamber **415**. For

example, the first orifice **420** and the second orifice **425** can directly face each other and share the same centerline C_L.

[0024] In one embodiment, the diameter of the first orifice **420** can be sufficiently smaller than the second orifice **425** to permit penetration of the first liquid stream into the second liquid stream. For example, the diameter of the first orifice **420** can be at least 10% less than the diameter of the second orifice **425** to provide adequate penetration of the first liquid stream into the second liquid stream.

[0025] In operation, a first liquid stream, represented by arrow **A**, can be introduced into the chamber **415** through the first orifice **420** thereby forming a liquid jet **430** (hereinafter referred to as "smaller liquid jet **430**" because this liquid jet exits the smaller diameter orifice **420**). Additionally, a second liquid stream, represented by arrow **B**, can be introduced into the chamber **415** through the second orifice **425** thereby forming a liquid jet **435** (hereinafter referred to as "larger liquid jet **435**" because this liquid jet exits the smaller diameter orifice **425**).

[0026] Both the smaller liquid jet **430** and the larger liquid jet **435** can flow into the chamber **415** where they can impinge along centerline C_L. Once the smaller liquid jet **430** and the larger liquid jet **435** collide, the smaller liquid jet **430** can penetrate and interact with the larger liquid jet **435** thereby creating a high shear intensity vortex contact layer **440** between the liquid jets **430, 435**. As a result of this penetration and interaction, cavitation caverns and bubbles are created in the high shear intensity vortex contact layer **440**. During the collapse of the cavitation caverns and bubbles, high localized pressures, up to 1000 MPa, arise and the level of energy dissipation in the chamber **415** attains a magnitude in the range of 1^{10} - 1^{15} watt/kg. Under these physical conditions in the liquid, on the boundary of the bubble and inside the bubble itself in the gas phase, chemical reactions proceed such as oxidation, disintegration, synthesis, etc. After the cavitation bubbles collapse, the liquid can exit through the outlet **417**, represented by arrow **C**.

[0027] It will be appreciated that any type of chamber may be provided with a pair of opposing jetting orifices to practice the present invention. Suitable type of chambers may include tank, a pipe, a spherical vessel, a cylindrical vessel such as a drum, or any other desired shape. It is also contemplated that any size and shape may be possible provided that the liquid

flow is permitted to enter the chamber. Such shapes may include cubical, conical, spherical, semi-spherical, or rectangular.

[0028] **FIG. 5** illustrates a longitudinal cross-section of one embodiment of a device **500** for creating hydrodynamic cavitation. The device **500** can include at least one wall **505** having an inner surface **510** that defines a flow-through channel or chamber **515**. For example, the wall **505** can be a cylindrical wall that defines a flow-through channel having a circular cross-section. It will be appreciated that the cross-section of flow-through channel **515** may take the form of other geometric shapes such as square, rectangular, hexagonal, or any other complex shape.

[0029] The flow-through channel **515** can further include an inlet **520** configured to introduce a liquid into the device **500** along a path, represented by arrow **A,** and an outlet **525** configured to exit the liquid from the device **500**.

[0030] In one embodiment, the wall **505** can include a first orifice **530** configured to permit the introduction of a first liquid stream into the flow-through channel **515** and a second opposing orifice **535** configured to permit the introduction of a second liquid stream into the flow-through channel **515**. For example, the first orifice **530** and the second orifice **535** can directly face each other and share the same centerline $\mathbf{C_L}$.

[0031] In one embodiment, the diameter of the first orifice **530** can be sufficiently smaller than the second orifice **535** to permit penetration of the first liquid stream into the second liquid stream. For example, the diameter of the first orifice **530** can be at least 10% less than the diameter of the second orifice **535** to provide adequate penetration of the first liquid stream into the second liquid stream.

[0032] In operation, a first hydrodynamic liquid stream moves along the direction, represented by arrow **A**, through the inlet **520** and flows into the flow-through channel **515**. As the liquid stream is passing through the flow-through channel **205**, a second liquid stream, represented by arrow **B**, can be introduced through the first orifice **530** forming a liquid jet **540** (hereinafter referred to as "smaller liquid jet **540**" because this liquid jet exits the smaller diameter orifice **530**) that flows into the flow-through channel **515**. Additionally, a third liquid

stream, reprssented by arrow **C**, can be introduced through the second orifice **535** forming a liquid jet **545** (hereinafter referred to as "larger liquid jet **545**" because this liquid jet exits the larger diameter orifice **535**) that flows into the flow-through channel **515**.

[0033] Both the smaller liquid jet **540** and the larger liquid jet **540** can flow into the flow-through channel **515** where they impinge along centerline $\mathbf{C_L}$. Once the smaller liquid jet **540** and the larger liquid jet **545** collide, the smaller liquid jet **540** can penetrate and interact with the larger liquid jet **545** thereby creating a high shear intensity vortex contact layer **550** between the liquid jets **540, 545**. As a result of this penetration and interaction, cavitation caverns and bubbles are created in the high shear intensity vortex contact layer **550**. During the collapse of the cavitation caverns and bubbles, high localized pressures, up to 1000 MPa, arise and the level of energy dissipation in the flow-through channel **515** attains a magnitude in the range of 1^{10} - 1^{15} watt/kg. Under these physical conditions in the liquid, on the boundary of the bubble and inside the bubble itself in the gas phase, chemical reactions proceed such as oxidation, disintegration, synthesis, etc. After the cavitation bubbles collapse, the liquid can be transported from the flow-through channel **515** and exit via the outlet **525**, represented by arrow **D**.

[0034] It will be appreciated that the aforementioned embodiments described above and illustrated in FIGS. 1-5 can be configured to receive liquid streams having the same or different characteristics, which can provide the operator with the ability to modify and control the desired cavitation effects. For example, the liquid streams discussed above may comprise the same liquid, different liquids, or any combination thereof. Each liquid stream may include a pure liquid, a liquid containing solid particles, a liquid containing droplets, an emulsion of multiple materials, a slurry, or a suspension. Additionally, each liquid may be introduced to the device under different physical conditions and chemical compositions. Such physical conditions may include pressure, flow rate, temperature, viscosity, and density. Such chemical compositions may include different chemical formulations and concentrations.

[0035] While the present invention has been illustrated by the description of embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art.

Therefore, the invention, in its broader aspects, is not limited to the specific details, the representative apparatus, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of the applicant's general inventive concept.